DOCUMENT RESUME

ED 458 784 EF 005 764

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TITLE	Energy Performance of Daylit Schools in North Carolina.
PUB DATE	1996-00-00
NOTE	8p.; Prepared by Innovative Design, Inc.
AVAILABLE FROM	For full text: http://www.innovativedesign.net/papers/papers.htm.
PUB TYPE	Reports - Evaluative (142)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Comparative Analysis; *Educational Facilities Design; Elementary Secondary Education; *Energy Management; *Light; Public Schools
IDENTIFIERS	*Cost Containment; *North Carolina

ABSTRACT

This study analyzes the energy performance and cost of daylit schools designed by Innovative Design in Johnston County, North Carolina. The analysis compares the first-year energy performances of the Clayton and Selma Middle Schools and the K-5 Four Oaks School with similar but non-daylit schools in Johnston County. The study analyses the characteristics of th daylit Clayton and Selma middle schools and comparisons to non-daylit schools, the cost of daylighting, dollar savings from daylighting, and Btu consumption. The study concludes that daylighting, even excluding all of the productivity and health benefits, makes sense from a financial investment standpoint. Daylit schools achieved energy cost reductions of between 22 percent to 64 percent over typical schools. Additionally, in North Carolina, a 125,000 square foot middle school that incorporates a well-integrated daylighting scheme is likely to save $40,000 per year compared to other schools not using daylighting. (GR)

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Energy Performance of Daylit Schools

ED 458 784

ENERGY PERFORMANCE OF DAYLIT SCHOOLS IN NORTH CAROLINA

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ABSTRACT

The following study analyzes the energy performance and cost of daylit schools designed by Innovative Design in Johnston County, North Carolina. The analysis compares the first-year energy performances of the Clayton and Selma Middle Schools and the K-5 Four Oaks School with similar but non-daylit schools in the County. The two daylit middle schools were completed in the spring of 1993 and the comparison year was July of 1993 through June of 1994. The Four Oaks School was completed in August of 1990 and the first year of collected data was 1991-92.

In addition to the three daylit schools listed above, cost information is also provided on two other daylit schools designed by Innovative Design - the Durant Road Middle School (Wake County, NC) and the Clayton Elementary School (Johnston County, NC). The Durant Road School was completed for the opening of the 1995-96 school year and first-year energy data is not yet available. Clayton Elementary is now under construction and nearing completion.

The K-5 Four Oaks School was constructed on an existing campus when the majority of the old school burned. Escaping the fire were classroom facilities that still serve the needs of the middle school students and a gymnasium which was integrated into the new K-5 construction. The renovated gymnasium as well as the cafeteria and outside athletic facilities are shared by both the K-5 students and the middle school students.

The two daylit middle schools are very similar in design, both based on a prototype design that incorporates extensive south-facing roof monitors. However, the Selma Middle School is approximately 22,000 square feet smaller and houses 150 less students. The Durant Road Middle School, although much larger, also includes many of the same design features incorporated in the Clayton and Selma Middle Schools. However, Durant utilizes both north and south facing roof monitors. The Clayton Elementary School is considerably different in design but also utilizes south-facing roof monitors as the major daylighting strategy.

In all cases, translucent fabric baffles are suspended in the lightwells to eliminate any direct beam radiation from entering into the work area below. Light sensors are used at each of the schools to stage the backup lighting. All of the schools are designed to achieve in excess of 70 footcandles, through daylighting, over two-thirds of the time the schools are occupied. Each classroom is also equipped with shades that can be used to darken the spaces and override switches to increase lighting levels. Although the shades and lighting override switches provide occasional functional benefits for individual classrooms, they are also the source of reduced daylighting benefit in certain classrooms.

The schools used in the comparison had, at the time of the analysis, the following characteristics:

a. the majority of space at each school was air-conditioned;

b. the schools were within the same County (a several county region was used in comparing cost of construction);

c. the majority of the space within the school was being utilized; and

d. the grade levels were similar.

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1. CHARACTERISTICS OF THE DAYLIT CLAYTON AND SELMA MIDDLE SCHOOLS AND COMPARISONS TO NON-DAYLIT SCHOOLS

Although attempts were made to compare the daylit schools to similar schools within the County, there were several significant energy related differences. Although the daylit schools performed extremely well, the following factors significantly increased the energy consumption and made the comparisons closer than otherwise would have been the case. Energy consumption in the daylit schools was abnormally high because:

a. the Clayton and Selma schools were the newest (and daylit) and they were utilized much more for extra-curricular activities and community events, accounting for considerably more night-time and weekend use;

b. the gymnasiums were extensively used during the summer and at night;

c. the schools were equipped with individual classroom TV/video monitors and communication systems;

d. more electrical equipment and computer technology was incorporated into the schools;

e. in the Four Oaks case, the gymnasium and cafeteria were shared with a middle school; and

f. the newer schools required considerably more fresh air make-up.

Both Clayton and Selma had central, natural gas boilers for heating and Four Oaks heating was with oil.

In all cases it appears that, even though the schools were not designed as year-around schools, they were occupied (at least by staff) most of the year.

2. THE COST OF DAYLIGHTING

The following lists both new daylit schools and non-daylit schools constructed in the immediate, several county region of North Carolina during the timeframe of our study. Taking into account the general trend of greatly escalating school construction costs, the daylit schools are very comparable. The highlighted schools indicate daylit schools designed by Innovative Design since 1990. In addition to the Clayton and Selma Middle Schools and the K-5 Four Oaks School, we have also included cost data on the Durant Road Middle School for Wake County and the Clayton Elementary School for Johnston County.

In all of these schools the cost of the daylighting components have added little to the first-cost of the projects. In the Durant Road Middle School the owner was particularly interested in calculating the energy cost versus savings attributed to the daylighting schemes employed. Through extensive cost estimating by an independent construction cost estimating firm, it was determined that the added cost of the daylighting features totalled $230,000. However, when one accounts for the $115,000 in mechanical equipment and electrical system downsizing possible because of the cooling and lighting load reductions, the net additional cost to the project was $115,000 - less than 1% of the total construction budget. The overall project, when completed, was 5% under budget and the daylighting/energy investment (when compared to typical new middle schools in the area) will be returned to the school system in less than a year.

Middle/High	Bid	Sq.ft	$/Sq.ft.
Clayton	**91**	**120,000**	**$ 65.26**
Selma	**92**	**98,000**	**$ 71.89**
Carrboro	92	136,266	$ 81.17
Davis Drive	93	132,000	$ 70.79
Durham	93	290,046	$ 72.35
Durant Road	**94**	**148,500**	**$ 83.04**
Chapel Hill	94	191,569	$107.19
Elementary	Bid	Sq.ft.	$/Sq.ft.
Four Oaks	**90**	**120,000**	**$ 55.02**
Cleveland	93	103,079	$ 71.93
Davis Drive	93	76,000	$ 72.57
Eastway	93	78,000	$ 83.22
Oak Grove	94	77,586	$ 90.95
Hodge Road	94	75,070	$ 89.37
Weatherstone	94	75,070	$ 93.18
Clayton	**95**	**96,800**	**$ 90.75**

In our latest school - the Clayton Elementary School, the daylighting components were bid as an alternate in order to clearly identify the actual costs associated with the daylighting. This was done at the request of the North Carolina Division of School Planning that was, at the time, very critical of daylighting. Through this effort it was again determined that the net cost difference, versus savings, would result in a very good investment for the school system. The total daylighting investment, based upon a simple payback, will be recouped in under three years.

In our earlier Four Oaks, Clayton and Selma schools, estimates indicated the investments in daylighting could be recaptured within three to nine years. Since these earlier projects, the improvements in cost-effectiveness can be mostly attributed to 1) the downsizing of conservatively sized mechanical and electrical equipment, 2) improvements in the roof framing design, and 3) improved lighting controls.

3. DOLLAR SAVINGS FROM DAYLIGHTING

The first year following the construction of the new Clayton and Selma Middle Schools the following energy consumption data was compiled between the daylit schools and several comparable, non-daylit schools. The school year starting in July 93 and ending June 94 had the following weather conditions:

a. Cooling Degree-Days were 12.3% above the norm

b. Heating Degree-Days were 5.1% above the norm

c. % Sunshine during the Cooling Season was 4.7% above the norm

d. % Sunshine during the Heating Season was 6.8% below the norm

These conditions would indicate an abnormally high energy bill for all the schools being compared but particularly the daylit schools which are impacted more by reduced sunshine in the heating season.

Energy Costs of Daylit Middle Schools in Johnston County (July 93 - June 94)

The following costs reflect:

(a) actual cost per square foot with all exterior lighting included

(b) cost if each school had same electrical rate of $.09/kwh

(c) cost with same electrical rates and exterior lighting loads subtracted

Daylit Schools	$/square feet			
	(a)	(b)	(c)	(*)
Clayton Middle	.90	.90	.84	(.71)
Selma Middle	.97	.92	.90	(.77)
Average Daylit	.94	.91	.87	(.74)

*In typical climatic years Clayton's cost would drop to $0.71/sq.ft. and Selma's cost would be $0.77/sq.ft., averaging $0.74/sq.ft. for the daylit schools.

Non-Daylit Schools	(a)	(b)	(c)
North Middle	1.00	1.03	1.00
Smithfield Middle	1.42	1.17	1.14
Smithfield-Selma HS	1.43	1.22	1.12
South HS	1.20	1.29	1.23
Average Non-Daylit	1.26	1.18	1.12
Savings/Sq.Ft.	**.32**	**.27**	**.25**

It is our conclusion that the measured energy savings between average daylit and non-daylit schools of $.32/square foot (or $.25 per square foot discounting utility price differences and exterior lighting) should be viewed as a minimum benefit since there are numerous factors relating to additional use (see 1 above) which, if all accounted for, would increase the benefit.

Lack of data and the existence of other elementary schools that are similar (i.e., other elementary schools did not have air-conditioning), prohibit an accurate comparison to other elementary schools in this first year of recorded data, but the following consumption data for Four Oaks was recorded during the 91-92 timeframe. During this timeframe the following weather conditions were experienced:

a. Cooling Degree-Days were 11.7% above the norm

b. Heating Degree-Days were 5.1% below the norm

c. % Sunshine during the Cooling Season was 6.1% below the norm

d. % Sunshine during the Heating Season was 6.5% below the norm

It should be noted that despite the higher than normal cooling degree-days, the facilities appeared to not be used as much during the summer months as they are in later years when summer use more than doubled. 1990-91 had 5.1% lower heating degree-days but also had 6.5% less winter sunshine.

Energy Costs of Daylit Four Oaks K-5 School (May 91-April 92)

Four energy cost scenarios, in energy $/square foot/year, reflect different ways of viewing the energy usage. The range between "C" and "D" represents the best estimate of the "building" energy cost associated with the K-5 component of the campus.

(a) Reflects actual bills which included all of the gymnasium, cafeteria, and exterior lighting

(b) Proportions gymnasium and cafeteria energy use between the middle school and the K-5

(c) Proportions gymnasium and cafeteria energy use and subtracts exterior lighting

(d) Same as (c) except estimated use of gymnasium and cafeteria reflects a high 75/25 split to account for additional middle school, community use and athletic events

Scenario	$/Sq.Ft./Year
(a)	$.53
(b)	$.46
(c)	**$.44**
(d)	**$.40**

The energy costs at Four Oaks are less than 40% of those experienced in other elementary schools (when air-conditioning was added in later years). For example, in 1993/94 (with similar energy costs for electricity and oil) the Clayton Primary School consumed $1.03/square foot and Benson Elementary used $1.11/square foot.

3.1 TRACKING THE BTU'S

At Four Oaks School the energy consumption in Btu's/square foot per year for the same four scenarios are listed below.

Energy Consumption of Daylit Four Oaks K-5 School (May 91 - April 92)

Level of Inclusion	Btu/Sq.Ft./Year
(a)	36,952
(b)	31,779
(c)	**30,984**
(d)	**28,396**
objective:	36,000

The objective of Innovative Design was to achieve, for the Four Oaks School, 36,000 Btu's/square foot per year. The 28,396 to 30,984 Btu/square foot range represents a 14% to 21% reduction from the objective. In Wake County (adjacent to Johnston County) eighty-seven separately monitored schools, during the same timeframe, consumed between 30,900 and 126,300 Btu's/square foot/year. This range in Wake County covered a wide variety of new and existing buildings with numerous mechanical, electrical and build shell differences.

At Clayton and Selma Middle Schools, like other middle schools, energy consumption would logically be greater. At Clayton the energy objective was to achieve 41,400 Btu's per square foot, based upon 9 months occupancy and normal nighttime and weekend use. As previously pointed out this did not turn out to be the case for either Clayton or Selma as utilization of the facilities was greater than anticipated.

The following reflects the actual energy consumed as well as different estimates of the effects of abnormal conditions and the impact of additional use. The 1993-94 year had 12% more cooling degree-days, 5% more heating degree-days, and 7% less sunshine during the heating season.

Energy Consumption of Daylit Clayton and Selma Middle Schools (July 93 - June 94)

(a) Reflects total energy use for campus including exterior lighting

(b) Same as (a) except exterior lighting is subtracted to reflect only the building load

(c) Same as (b) except this reflects a correction to account for typical heating and cooling degree-days as well as percent sunshine

(d) Same as (c) except consumption attempts to account for a 50% reduction in summertime energy use, more closely reflecting a typical 9-month school schedule

Scenario	Btu/Sq.Ft./Year	
	Clayton	Selma
(a)	53,443	53,114
(b)	51,168	50,502
(c)	47,315	47,486
(d)	**43,731**	**44,282**
objective:	41,400	

4. CONCLUSIONS

The most obvious conclusion is that daylighting, even excluding all of the productivity and health benefits, makes sense from a financial investment standpoint. The daylit schools in the study indicated energy cost reductions of between 22% to 64% over typical schools. With paybacks on all the new daylit schools below three years, the long term benefits to a school system are enormous. In North Carolina, a 125,000 square foot middle school that incorporates a well integrated daylighting scheme is likely to save $40,000 per year over what is typically constructed. And, if energy costs go up by 5% per year, the savings on just this one school, over the next ten years, would exceed $500,000.

From an analytical standpoint, it also appears wise to assume that:

a. even though the school program calls for a nine month schedule, anticipate the school will be occupied for twelve months;

b. public spaces (i.e., gymnasiums, cafeterias and libraries) will be utilized considerably more than is needed to fulfill just the students' class needs;

c. internal loads due to computers and other electrical equipment will greatly exceed amounts typical of previous years;

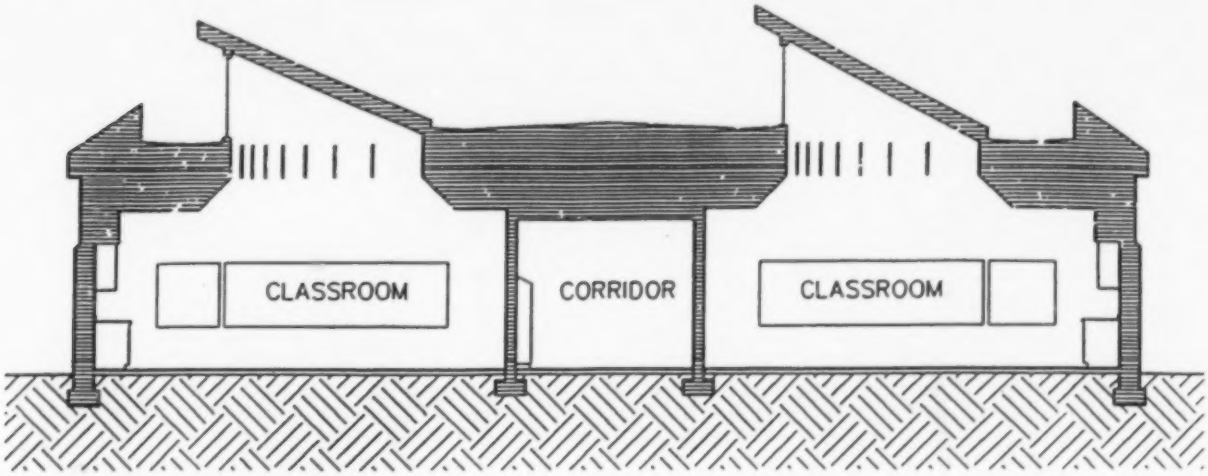
d. new requirements for fresh air make-up will drastically impact energy consumption;

e. indoor temperatures, if individual room controls are provided, will routinely exceed 70_F in the winter and 76_ in the warmer months; and

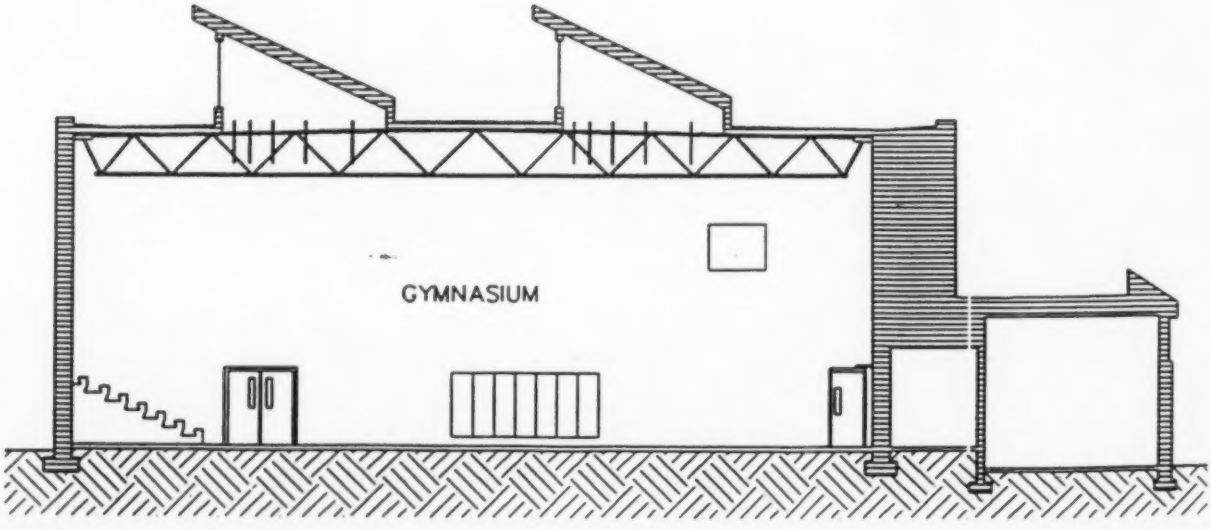
f. that the daylighting performance, even though controlled by light and motion sensors, will ultimately be determined by the teachers and, in particular, the schools' principals that greatly influence attitudes.

5. REFERENCES

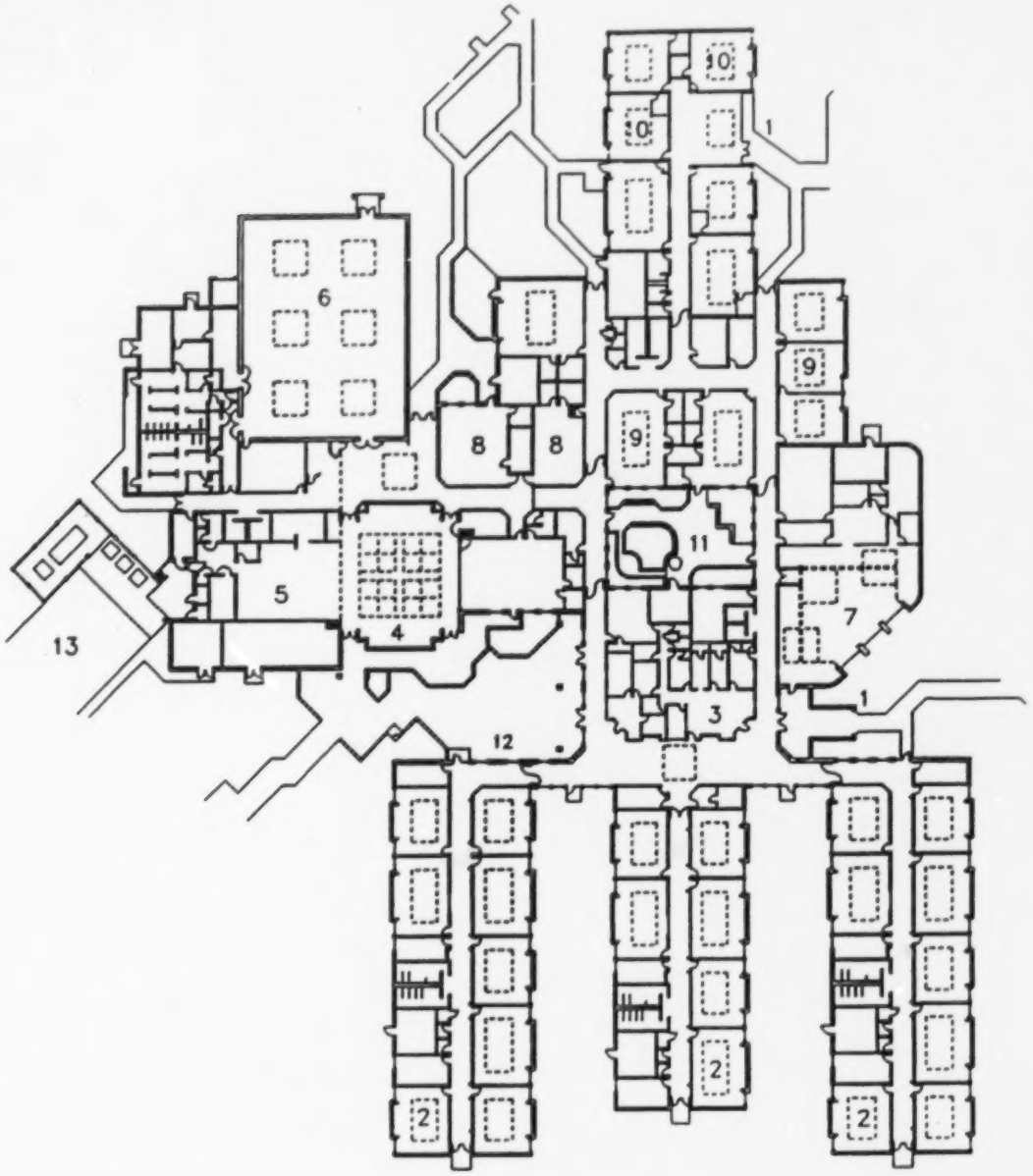
Johnston County Energy Consumption Data, Johnston County Schools' Maintenance Department, January, 1996.



Classroom Daylighting



Gymnasium Daylighting



Plan Key

1	Entrance	7	Media Center
2	Classroom	8	Performing/Visual Arts
3	Administration	9	Resource Classroom
4	Cafetorium	10	TMH Classroom
5	Kitchen	11	Teaching Courtyard
6	Gymnasium	12	Bus Drop Courtyard
		13	Searvice Entrance